

CAN WE REACH AGREEMENT ON A STANDARDIZED APPROACH TO ECOSYSTEM-BASED FISHERY MANAGEMENT?

Elizabeth A. Babcock and Ellen K. Pikitch

ABSTRACT

In the 25 yrs since the Magnuson Fisheries Conservation and Management Act was passed, substantial agreement has been reached about how to manage single-species fisheries in the U.S. Biological reference points, such as the biomass that will produce maximum sustained fisheries yield, are estimated from fairly standardized kinds of fisheries models, and management regulations such as quotas are set according to control rules based on these reference points. Debate about the specifics of single-species fisheries management takes place within this basic framework. However, the objectives, principles, goals, and scientific methodology of ecosystem-based management are in an early stage of development, and no standardized approach currently exists. Ecosystem-based management regimes may run the gamut from a suite of single-species reference points to that based on reference points that measure some level of ecosystem function (e.g., measures of biodiversity). Management regimes that do not rely upon quantitative reference points, such as systems of marine protected areas, gear restrictions, or community-based management, have also been referred to as ecosystem-based management. Inclusion of ecosystem values such as biodiversity and ecosystem function in fisheries management under U.S. fisheries law will require evolution of consensus toward a standardized, practical approach to ecosystem-based management.

Some form of ecosystem-based fishery management (EBFM) or at least incorporation of ecosystem principles into management is required by a many recent laws, treaties, and agreements, such as the U.N. agreement on Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, the U.S. Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), and the Plan of Implementation from the recent World Summit on Sustainable Development 2002 in Johannesburg. These legal requirements provide a practical reason why fisheries scientists must reach a consensus on what an ecosystem approach to fisheries management means. At the same time, many scientists, recognizing the widespread failures of traditional fisheries management, have advocated some form of EBFM as a solution. Many review papers, meetings, and advisory panels have been devoted to consideration of these issues and their potential application to fisheries management, but they have advocated (or argued against) a range of concepts under the ecosystem banner, and many have produced a “laundry list” of desired elements. For example, in 1998 the National Marine Fisheries Service convened an Ecosystem Principles Advisory Panel to advise NMFS on how to comply with the MSFCMA requirement for NMFS to consider ecosystem principles in fisheries management. The panel concluded that a Fisheries Ecosystem Plan should:

- (1) “Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical and physical dynamics of those ecosystems, and ‘zone’ the area for alternative uses.

- (2) Develop a conceptual model of the food web.

- (3) Describe the habitat needs of different life history stages for all plants and animals that represent the ‘significant food web’ and how they are considered in conservation and management measures.

(4) Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yields, natural mortality and trophic structure.

(5) Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

(6) Develop indices of ecosystem health as targets for management.

(7) Describe available long-term monitoring data and how they are used.

(8) Assess the ecological, human, and institutional elements of the ecosystem which most significantly affect fisheries, and are outside Council/Department of Commerce (DOC) authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives”(U.S. National Marine Fisheries Service Ecosystem Principles Advisory Panel, 1999: 3–4).

As U.S. fishery management councils incorporate this guidance into fishery ecosystem plans (e.g., Western Pacific Regional Fishery Management Council, 2001; NOAA Chesapeake Bay Office, 2001), they have varied greatly in which of the eight elements they have included and how they have addressed them. This diversity of implementation reflects a lack of consensus on the key scientific elements of EBFM and a lack of resolution on its specific applications and utility for improving the conservation and management of marine ecosystems.

For EBFM to become the basis of fisheries management, the concept will have to be sufficiently simple, unified, and compelling to replace the current single-species fisheries management philosophy.

THE CONSENSUS OF SINGLE-SPECIES MANAGEMENT

In the 25 yrs since the Magnuson Fisheries Conservation and Management Act was passed, substantial agreement has been reached about how to manage single-species fisheries in the U.S. Most single-species fisheries-management systems can be described by a generalized management framework that includes the following elements (Restrepo et al., 1998; Sainsbury et al., 2000; Murawksi, 2000; Mace, 2001):

1. Target and limit biological reference points (BRPs). Biological reference points are levels of biomass, fishing mortality rate, or other characteristics of a fish population and a fishery that are either the target of management or a limit beyond which the fishery will not be permitted to go (e.g., overfishing thresholds).

2. Performance indicators. Performance indicators are measures of the status of a fish stock with respect to the biological reference points. They measure how well a management strategy is performing its stated goal of achieving target biological reference points and avoiding limit biological reference points.

3. Control rules (= decision rules). A control rule is an algorithm by which the values of performance indicators with respect to biological reference points will be translated into management decisions.

The values of biological reference points and performance indicators are estimated through fisheries stock assessments, which combine fisheries and biological data with a model of fish population dynamics. The population dynamics model is then used to predict the possible consequences of proposed management actions. Managers choose a control rule that has a good chance of achieving target reference points and/or avoiding limit reference points, given the existing uncertainties.

In the U.S., there is little disagreement about the general framework for management. The MSFCMA National Standard 1 requires fisheries management to “prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry,” where “optimum yield” is defined as “the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor.” This standard has led to target and limit biological reference points related to the biomass that will sustain the maximum sustainable yield (MSY). Performance indicators are generally the biomass or fishing mortality rate relative to the reference points, estimated by one of a limited number of assessment methodologies. Quotas are the most common form of management for rebuilding overfished populations.

Part of the appeal of this management approach is its simplicity. The objective of rebuilding a population to a level that will sustain a high long-term average yield is easy to understand and does not require justification. EBFM will not be a viable replacement for current single-species management until it can develop an equally simple and compelling management philosophy (Larkin, 1996; Mace, 2001). In the interest of developing a consensus, we suggest three possible routes and discuss what a consensus might look like for each route.

1. PROTECTION OF LARGE AREAS: DOES EBFM MEAN THROWING OUT STOCK ASSESSMENT, BRPs, AND CONTROL RULES?

The traditional single-species management system includes assumptions, such as

- (1) the objective of management is to maximize the long-term average yield of each fishery;
- (2) a population biomass level exists that will maximize the long-term average yield;
- (3) the population's status relative to the biomass level that will sustain MSY can be determined;
- (4) fish growth, natural mortality, and fecundity are constant and do not change over time, irrespective of the abundance of other species, environmental changes, or the effects of fishing;
- (5) the total fishing mortality can be controlled by regulation of the fishery;
- (6) the consequences of management actions can be predicted so that a correct management action can be taken.

Some authors (Walters, 1998; Stergiou, 2002) have argued that the system is inherently flawed. Walters (1998) argued that management strategies that use catch quotas to manage for a target biomass level will not be successful unless stock assessments are accurate, which they often are not. Stergiou (2002) argued that single-species stock-assessment models are flawed because they fail to acknowledge that growth and other biological factors change over time, both because of food web interactions and other natural processes and because of the effects of fisheries, implying that reference points based on long-term average yields are unrealistic. Multispecies models, although they would be more realistic for including ecosystem effects, would not necessarily be better at predicting changes in ecosystems over time. Stergiou (2002) and Walters (1998) believe that, rather than developing more and more complex models and management schemes, fisheries should just be managed by establishment of large-scale closed areas.

The idea of using marine protected areas (MPAs) instead of traditional fisheries management is rather radical because it would involve fundamental changes in the practice of fisheries science and management. This may be one reason that most authors have advocated MPAs as a supplement to traditional management rather than a replacement

(e.g., National Research Council, 2001), but the area-closure approach may be more effective than classical management for some fisheries. For example, a system of marine reserves has been shown to increase the catch per unit effort in a tropical small-scale fishery, even in the absence of catch quotas (Roberts et al., 2001). Besides MPAs, gear restrictions, stringent effort controls, or seasonal closures could be used to reduce the impact of fisheries on marine species and ecosystems so that information-intensive assessments and management would not be necessary.

In essence, the argument for simply closing off large areas to fisheries is that the traditional single-species models are promising what they cannot deliver, the ability to predict the future so that correct management decisions will allow the fishery to arrive at the desired population. That ecosystem models will ever predict the future even as well as single-species models seems doubtful given the increased complexity and data needs of ecosystem models. The idea of management systems that are more precautionary and require less information therefore deserves to be taken seriously, but for this approach to evolve into the consensus definition of EBFM, what sort of scientific consensus would be required? Although the justification for this approach is that it does not depend on predictive models, science would still need to contribute a methodology for developing zoning systems that would effectively protect ecosystems and fish stocks while still allowing fisheries to continue. Methods exist for reaching agreement among stakeholders in the process of establishing systems of MPAs (e.g., Craik, 1996), but little theory or experimental evidence is available to predict the effect of large-scale zoning on fisheries yields, which would seem to be a necessary step in developing management schemes based on closed areas.

2. SINGLE-SPECIES MANAGEMENT PLUS: COULD EBFM INCLUDE THE SAME SINGLE-SPECIES ASSESSMENTS AND CONTROL RULES PLACED IN AN ECOSYSTEM CONTEXT?

Perhaps the easiest form of EBFM to implement would involve the continued use of single-species reference points and stock-assessment models to manage the species within an ecosystem, while also adding ecosystem considerations to management plans. EBFM could be achieved by use of single-species reference points to manage nontarget species, including by-catch species, protected species, and even benthic communities, particularly if MPAs were used to protect benthic habitats from the effects of mobile fishing gear (Hall, 1999). Keeping the ecologically important species in an ecosystem above their single-species limit reference points seems likely to maintain biodiversity and other measures of ecosystem health fairly well (Mace, 2001).

A focus on single-species reference points would not preclude the use of ecosystem models to improve management. Collie and Gislason (2001) examined how well single-species BRPs derived under single-species assumptions perform in an ecosystem context. They used a multispecies population dynamics model called MSVPA to test effects of several predator-prey scenarios on various single-species reference points in the North Sea Atlantic cod–herring–sprat ecosystem. The BRP's tested were sensitive to changes in natural mortality rates caused by food-web dynamics (Collie and Gislason, 2001). Their study implies that it would be possible to improve fishery management either by choosing BRPs that are robust to food web effects or by explicitly accounting for food-web effects in stock assessment.

Part of the argument for the “single-species plus” approach is that single-species management has a well-developed theory and modeling approaches. The failures of single-species management have not necessarily been caused by a lack of consideration for

ecosystem principles. Rather, as Mace (2001) pointed out, it has often failed because it has not followed its own principles; fishing mortality rates are often above the limits set by single-species control rules. Ecosystem “health” might be improved as much or more by management designed to keep many individual species above their “overfished” reference points rather than to manage ecosystems as a whole (Mace, 2001). Perhaps the best approach would be to continue using single-species control rules but to add ecosystem limit reference points, as suggested by Murawski (2000). If an “ecosystem overfishing” limit reference point were reached, managers would be required to take immediate action to restore the ecosystem; otherwise, single-species management could continue as usual. Combined with standards for protection of by-catch species and benthic habitat this could be a sufficiently “ecosystem-based” management scheme.

If “single-species plus” is the EBFM scheme chosen, the problem arises that no consensus has been reached about the features of ecosystems that should be maintained (see below). More importantly, however, we do not yet have an objective way to weight the objectives of maximizing fisheries yield and maintaining ecosystem health. One danger of the “single-species plus” approach is that ecosystem considerations might end up being another chapter added to fishery management plans without actually improving the management of fisheries. To prevent ecosystem considerations from being marginalized in management plans, ecosystem objectives should be incorporated into the plan’s goals and objectives, with a clear set of ecosystem standards that a management action or set of actions must support. EBFM principles should require action, in the same way that the single-species overfishing definitions require action.

The “single-species plus” approach does not address one of the most interesting ideas to come out of the recent round of fisheries ecosystem research, the idea that rebuilding ecosystems from their current, damaged condition to a healthier condition would greatly benefit fisheries (Pitcher et al., 1999; Jackson et al., 2001). If the consequences of this idea are to be examined, ecosystem-based metrics must be considered.

3. ECOSYSTEM REFERENCE POINTS AND CONTROL RULES: HAS ECOSYSTEM SCIENCE EVOLVED TO A LEVEL AT WHICH IT CAN REPLACE SINGLE-SPECIES MANAGEMENT?

If a new management scheme based on ecosystems is to replace management of individual species, presumably National Standard 1 or some other standard related to fisheries yield would remain an objective of management. Maintaining biodiversity or some other measure of ecosystem health would also be an important objective. In either case, to manage ecosystems instead of single species will require ecosystem-based biological reference points, performance indicators, and control rules that are based on assessment of ecosystem status and predictive ecosystem models (Murawski, 2000). If maximizing fisheries yield were to remain an objective, a methodology for translating ecosystem health into expected fisheries yields would also be necessary (see, e.g., Pitcher et al., 1999). The majority of the current literature on EBFM is focused on addressing these technical issues (Done and Reichelt, 1998; Hall, 1999; Pitcher et al., 1999; Murawski, 2000; Rice, 2000; Sainsbury et al., 2000; Mace, 2001), although no authors have yet concluded that the assessment methodology exists to allow management based on ecosystem metrics to replace single-species approaches completely.

To name just a few examples from this developing literature, Rice (2000) developed a taxonomy of metrics of community structure, with four broad categories: (1) diversity indices based on species richness, evenness, and dominance; (2) ordination methods applied to species composition data; (3) aggregate indicators of ecosystem status such as

biomass size spectra; and (4) “emergent property” metrics, which are derived from ecosystem models. Possible metrics include the mean trophic level of the fishery catch from mass-balance models like Ecosim/Ecopath and the stability (persistence of nodes) and resistance to perturbation of a food-web model (Rice, 2000). Done and Reichelt (1998) suggested several diversity metrics that are weighted by desirable characteristics of species in an ecosystem. For example, because fishing tends to remove fish selectively from higher trophic levels, a proposed index of trophic structure would sum the proportion of biomass weighted by its trophic level, so that higher numbers would indicate less fishing. Some theoretical studies have examined the effect of fishing on proposed ecosystem metrics. Bianchi et al. (2000) compared various fisheries for cross-system differences in the slope and intercept of size spectra that could be related to fishing. They concluded that the slope of the size spectrum does give a crude indicator of exploitation level.

Given that a metric of ecosystem health can be found, a model will be needed that can be used to predict how the ecosystem will react to proposed management actions (Murawski, 2000; Mace, 2001). At present, the only possibilities seem to be mass-balance models like Ecosim/Ecopath (Pauly et al., 2000) and multispecies population-dynamics models like MSVPA (Collie and Gislason, 2001). These models have not yet been demonstrated to perform as well as single-species models in predicting the future (Mace, 2000, 2001), but the methods are rapidly improving in their ability to capture important ecosystem processes and in the number of ecosystems that have been modeled. An interesting development is “Ecoval” (Pitcher et al., 1999), a new methodology derived from the Ecopath family of models, which can be used to determine the economic value to society of alternative ecosystem states. This methodology could potentially be used to manage an ecosystem for maximum economic benefit, a direct analogy to traditional single-species management.

Current research efforts could probably lead to the development of ecosystem-based BRP’s, performance indicators, and control rules, along with the ecosystem models necessary to predict the impact of management action. Fisheries science is approaching a state of knowledge in which EBFM based on ecosystem metrics is technically feasible. Many arguments support this approach, including (1) that a healthier ecosystem would be more stable and more resilient to environmental changes, (2) that total economic benefits from healthy ecosystems would be higher, and (3) that ecosystem models would be more realistic than single-species models, which ignore ecosystem effects, leading to better management decisions. Arguments against the approach include (1) that it has intensive data requirements, (2) that ecosystem models are overly complex and thus unlikely to perform well, and (3) that it is very difficult to agree on target ecosystem characteristics.

An EBFM that includes ecosystem-based metrics and predictive models is the most scientifically intriguing of the possible management schemes. It also raises the possibility of great improvements in fisheries yields, not just maintenance of the status quo (Pitcher, 2001). Nevertheless, fisheries scientists seem far from reaching a consensus on how to define the ecosystem-based BRPs, performance indicators, and control rules that would be needed for this approach. Murawski (2000) concluded that it would be impossible to find a single metric that captures every conceivable ecosystem goal related to biomass, diversity, variability, and social and economic benefits. This is certainly true, but it is also true that MSY-based control rules do not capture all the objectives of conventional management; they capture only the objective of maximizing fisheries yield. In

principle, it seems possible to derive a single metric, incorporating both economic goals and ecosystem health, that could replace single-species control rules.

CONCLUSION

Several U.S. fishery management councils are in the process of developing (or have already developed) fishery ecosystem plans consistent with the recommendations of the the NMFS Ecosystem Principles Advisory Panel (U.S. National Marine Fisheries Service Ecosystem Principles Advisory Panel, 1999). Of those recommendations, the first one (zoning the area for alternative uses) would be the most important for a management scheme based on large-area closures. The recommendations to develop a conceptual model of the food web and ecosystem metrics as targets of management would be critical components of a management scheme based on ecosystem metrics. The panel's report is a step forward in that it articulates many of the ecosystem issues that have been neglected in fisheries management, but the panel did not favor any particular management scheme.

The importance of both maintaining ecosystem function and considering ecosystem processes in fisheries management is now widely accepted. The current boom in ecosystem-based research will certainly improve fishery management by improving our understanding of how ecosystem processes affect the population dynamics of exploited fish. Nevertheless, ecosystem-based fishery management is still at the stage where it can include a wide range of different and sometimes contradictory objectives, principles, and methodologies. For EBFM to replace single-species management as the conceptual basis of U.S. fisheries management, it must move beyond theory and lists of objectives; a straightforward and compelling conceptual framework must be an agreed upon. The final EBFM consensus may be similar to one of the three strategies listed above, or it may be something different, but it must have a clear definition before it can become useful.

ACKNOWLEDGMENTS

This project was initiated and supported by The Pew Charitable Trusts, while the authors were employed by the Wildlife Conservation Society. E.A.B.'s work was funded in part by the Constantine S. Niarchos Fellowship in Marine Conservation. We thank R. Bonfil and E. Lauck for comments on an early draft.

LITERATURE CITED

- Bianchi, G., H. Gislason, K. Graham, L. Hill, X. Jin, K. Koranteng, S. Manickchand-Heileman, I. Paya, K. Sainsbury, F. Sanchez, and K. Zwanenburg. 2000. Impact of fishing on size composition and diversity of demersal fish communities. *ICES J. Mar. Sci.* 57: 558–571.
- Collie, J. S. and H. Gislason. 2001. Biological reference points for fish stocks in a multispecies context. *Can. J. Fish. Aquat. Sci.* 58: 2167–2176.
- Craik, W. 1996. The Great Barrier Reef Marine Park, Australia: a model for regional management. *Nat. Areas J.* 16: 344–353.
- Done, T. J. and R. E. Reichelt. 1998. Integrated coastal zone and fisheries ecosystem management: generic goals and performance indices. *Ecol. Appl.* 8: S110–S118.
- Hall, S. J. 1999. Managing fisheries within ecosystems: can the role of reference points be expanded? *Aquat. Conserv.* 9: 579–583.
- Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. Botsford, Z. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S.

- Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293: 629–639.
- Larkin, P. A. 1996. Concepts and issues in marine ecosystem management. *Rev. Fish Biol. Fish.* 6: 139–164.
- Mace, P. M. (ed). 2000. Proceedings of the 6th NMFS National Stock Assessment Workshop: incorporating ecosystem considerations into stock assessments and management advice: what are the pros and cons of going beyond single species? NOAA Tech. Memo. NMFS-F/SPO-46. U.S. Dept. Commerce, Washington, D.C. 78 p.
- _____. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish Fish.* 2: 2–32.
- Murawski, S. A. 2000. Definitions of overfishing from an ecosystem perspective. *ICES J. Mar. Sci.* 57: 649–658.
- National Research Council. 2001. Marine protected areas: tools for sustaining ocean ecosystems. Natl. Academy Press, Washington, D.C. 272 p.
- NOAA Chesapeake Bay Office. 2001. Chesapeake Bay fisheries ecosystem plan workshop report. NOAA Chesapeake Bay Office, Solomons. 93 p.
- Pauly, D., V. Christensen, and C. Walters. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES J. Mar. Sci.* 57: 697–706.
- Pitcher, T. J. 2001. Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecol. Appl.* 11: 601–617.
- _____, N. Haggan, D. Preikshot, and D. Pauly. 1999. “Back to the future”: a method employing ecosystem modelling to maximize the sustainable benefits from fisheries. Pages 447–465 in *Ecosystem approaches for fisheries management*. Alaska Sea Grant Report AK-SG-99-01. Univ. Alaska, Fairbanks, Alaska.
- Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. I. Taylor, P. R. Wade, and J. F. Wiltzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fisheries Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31. U.S. Dept. Commerce, Washington, D.C. 54 p.
- Rice, J. C. 2000. Evaluating fishery impacts using metrics of community structure. *ICES J. Mar. Sci.* 57: 682–688.
- Roberts, C. M., J. A. Bohnsack, F. Gell, J. P. Hawkins, and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. *Science* 294: 1920–1923.
- Sainsbury, K. J., A. E. Punt, and A. D. M. Smith. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. *ICES J. Mar. Sci.* 57: 731–741.
- Stergiou, K. I. 2002. Overfishing, tropicalization of fish stocks, uncertainty and ecosystem management: resharpening Ockham’s razor. *Fish. Res. (Amst.)* 55: 1–9.
- U.S. National Marine Fisheries Service Ecosystem Principles Advisory Panel. 1999. Ecosystem-based Fishery Management, A Report to Congress. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C. 54 p.
- Walters, C. 1998. Designing fisheries management systems that do not depend on accurate stock assessment. Pages 279–288 in T. J. Pitcher, P. J. B. Hart, and D. Pauly, eds. *Reinventing fisheries management*. Kluwer, Dordrecht.
- Western Pacific Regional Fishery Management Council. 2001. Final fishery management plan for coral reef ecosystems of the western Pacific region. Western Pacific Regional Fishery Management Council, Honolulu.

ADDRESS: *Pew Institute for Ocean Science, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149. E-mail: <bbabcock@rsmas.miami.edu>.*